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Morphometric Analysis of the Wrist on Posteroanterior Radiographs: Age and Sex-Related Variations in a Turkish Population

Análisis Morfométrico de la Articulación Radiocarpiana en Radiografías Posteroanteriores: Variaciones Relacionadas con la Edad y el Sexo en una Población Turca

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SUMMARY: This study aimed to establish normal reference values for wrist bone morphometry on posteroanterior radiographs in individuals aged 20–74 years, and to analyse how these values and derived wrist-related ratios vary by age and gender. The study was conducted using bilateral posteroanterior wrist radiographs from 300 healthy individuals. The lengths and angles of the wrist bones were measured using the Horos Medical Viewer programme, and wrist ratios were calculated based on these measurements. Participants were categorised into three age groups: 20–39, 40–59, and ≥60 years. Data were analysed according to both age and sex. All length measurements, as well as the carpal angle, carpal-height ratio, carpal-radial ratio, and carpal-ulnar ratio, were statistically significantly higher in males than in females ($p < 0.001$). Age group analysis showed that individuals aged 20–39 years had lower left carpal height and carpal–radial distance compared to older groups ($p < 0.05$). Ratio analyses further revealed significantly lower carpal height, carpal-radial ratio, and carpal-ulnar ratio in the 20–39 age group, while no significant age-related differences were observed in angular parameters or most linear measurements. Wrist morphometric measurements are widely used in the diagnosis and evaluation of wrist pathologies. Therefore, establishing normal reference values specific to different populations and age groups is essential. We believe that our study will provide a useful reference for future research in this field.

KEY WORDS: Wrist; Carpal bones; Radiography; Reference values; Turkey.

INTRODUCTION

The wrist joint is among the most frequently used joints in daily activities, rendering it highly vulnerable to traumatic injuries and degenerative disorders. Due to its complex anatomy encompassing vital structures such as blood vessels, nerves, and tendons comprehensive knowledge of its anatomy, morphometry, and biomechanical characteristics is essential for accurate clinical evaluation and effective treatment planning (Açıkgöz *et al*., 2022).

Clinicians use carpal indices and morphometric measurements to diagnose and manage wrist conditions, such as distal radius fractures, Kienböck's disease, carpal instability, carpal bone fractures, carpal tunnel syndrome, and ulnar impaction syndrome (Bhat *et al*., 2024). Wrist pathologies are commonly assessed using posteroanterior (PA) and lateral radiographs, dynamic imaging, or computed tomography. Despite advances in imaging techniques, plain radiographs remain the most widely used and preferred initial method for visualising the bony structures of the wrist. Radiographic wrist measurements have been employed since 1978, when Youm *et al*. (1978) first introduced parameters such as carpal height (CH), carpal-height ratio (CHR), and carpal-ulnar distance (CUD) (Jehan *et al*., 2019). These radiological parameters vary significantly in the presence of wrist pathologies; therefore, their evaluation is valuable for diagnosing and planning the treatment of wrist disorders, as well as for monitoring treatment outcomes (Ominde *et al*., 2022). Given the diagnostic and therapeutic importance of radiographic wrist measurements, establishing population- and ethnicity-specific reference values is essential. However, knowledge about wrist bone morphometry and age- and sex-related variations in the Turkish population remains limited.

This study aimed to evaluate selected morphometric characteristics and wrist-related ratios derived from posteroanterior wrist radiographs in individuals aged 20–74 years and to establish population-based reference values by examining differences according to sex and age.

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MATERIAL AND METHOD

Procedure

This retrospective study included 300 individuals, comprising 150 males and 150 females, aged 20–74 years, who presented to the Ondokuz Mayis University Health Application and Research Center without wrist pathology and underwent posteroanterior radiographs of the hand and wrist. Bilateral PA wrist radiographs were evaluated, and individuals were categorized into age groups: 20–39, 40–59, and ≥60 years, according to biological stages of adulthood and the onset of age-related degenerative changes.

Individuals aged 75 years and older were excluded from the study to minimise the potential influence of advanced age-related degenerative changes on measurement outcomes. With increasing age, degenerative conditions such as osteoporosis, osteoarthritis, and subchondral sclerosis become more prevalent and can cause significant alterations in bone morphometry. These changes may lead to measurement inconsistencies and complicate the establishment of reliable anatomical reference values.

The study was approved by the Ondokuz Mayıs University Clinical Research Ethics Committee (Approval No: 2020/685) and conducted in accordance with the Declaration of Helsinki.

Wrist radiographs were obtained in a standardised PA projection at a fixed distance of 90 cm, using uniform exposure settings (48 kV, 3.2 mAs). Individuals with a history of surgery or trauma, musculoskeletal or congenital anomalies of the hand, or wrist-related pathologies (e.g., arthritis, bone tumours, and carpal tunnel syndrome) were excluded from the study.

Morphometric measurements were performed digitally on the radiographs using Horos Medical Viewer software (Version 3.3, USA). All measurements were conducted by a single investigator and repeated three times at different time points, and the mean values were recorded. Linear measurements were expressed in millimetres (mm) and angular measurements in degrees (°). Wrist-specific anatomical ratios (carpal height ratio, revised carpal height ratio, carpal-radial ratio, and carpal-ulnar ratio) were calculated based on the obtained linear values.

Morphometric Measurements

Hand length (HL, Fig.1): The distance from the midpoint of a line connecting the radial and ulnar styloid processes (corresponding to the midpoint of the distal wrist crease) to the tip of the third digit (Karaman *et al*., 2008).

Third metacarpal bone length (TMCL, Fig.1): The distance between the proximal-most and distal-most points on the third metacarpal (Bhat *et al*., 2024).

Capitate length (CL, Fig.1): Measured along the longest axis of the capitate, from its proximal to distal ends. The axis was determined by the intersection of the capitate with the second and third metacarpals at the distal articular surface, with a line drawn to the proximal cortex (Bhat *et al*., 2024).

Carpal height (CH, Fig.1) : The distance from the distal articular surface of the radius to the base of the third metacarpal bone (Bhat *et al*., 2024).Scaphoid length (SL): The distance between the distal and proximal poles along the longitudinal axis of the scaphoid bone (Vaezi *et al*., 2017).

Lunate width (LW, Fig.1): The maximum transverse diameter of the lunate, aligned with the distal radius (Vaezi *et al*., 2017).

Carpal radial distance (CRD, Fig.1): The distance between a line passing through the radial styloid process and the rotational centre of the wrist (Mohammed Ali, 2009).

Carpal ulnar distance (CUD, Fig.1): The distance between the longitudinal axis passing through the most prominent distal point of the ulna and the rotational centre of the wrist (Mohammed Ali, 2009).

Carpal-height ratio (CHR, Fig.1): Calculated by dividing the CH by the length of the third metacarpal bone (Youm *et al*., 1978).

Revised carpal-height ratio (rCHR, Fig.1): Determined by dividing the CH by CL (Nattrass *et al*., 1994).

Carpal-radial ratio (CRR, Fig.1): Calculated by dividing the carpal radial distance by the length of the third metacarpal bone length (Mohammed Ali, 2009).

Carpal-ulnar ratio (CUR, Fig.1): Calculated by dividing CUD by the length of the third metacarpal bone length (Mohammed Ali, 2009).

Radial inclination angle (RIA, Fig.2): The angle formed between a vertical line along the longitudinal axis of the radius and a line drawn from the radial styloid to the ulnar aspect of the distal radius (Mohammed Ali, 2009).

Carpal angle (CA, Fig.2): The angle formed by the intersection of two lines tangential to the proximal margins of the lunate and triquetrum bones (Harper *et al*., 1974).

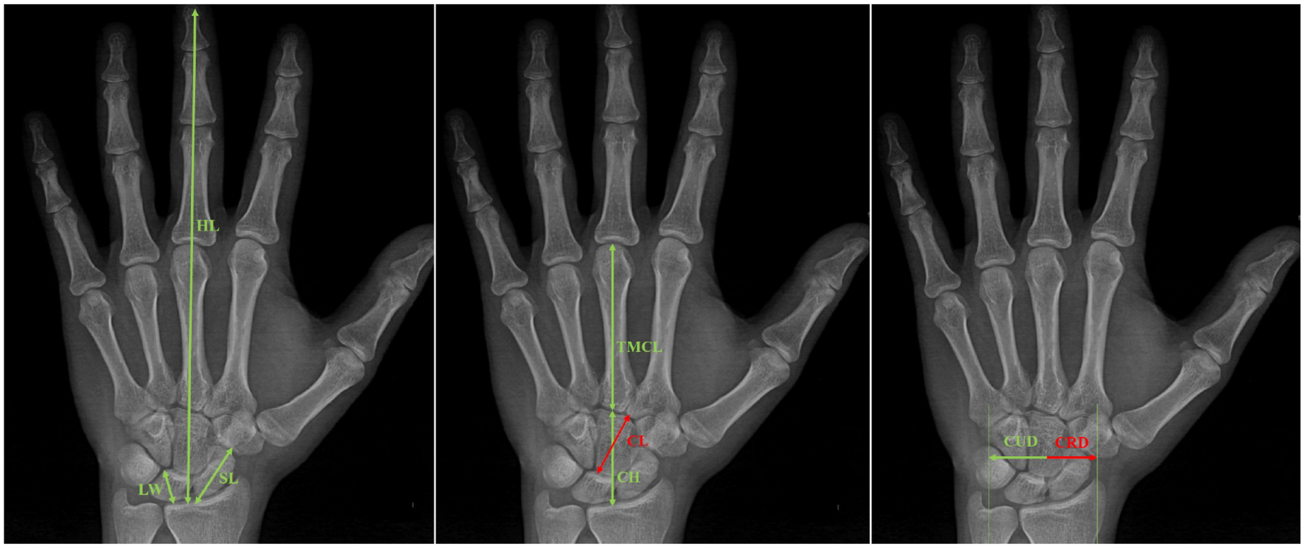

Fig. 1. Linear measurements of the wrist. HL: hand length, TMCL: third metacarpal bone length, CL: capitate length, CH: carpal height, SL: scaphoid length, LW: lunate width, CRD: carpal radial distance, CUD: carpal ulnar distance, CHR: CH/TMCL, rCHR: CH/CL, CRR: CRD/TMCL, CUR: CUD/TMCL

Fig. 2. Angle measurements of the wrist. RI: radial ınclination angle, CA: carpal angle.

Statistical analysis. All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS, Version 20.0; IBM Corp., Armonk, NY, USA). Statistical significance was set at $p < 0.05$ with a 95 % confidence interval. The normality of data distribution was assessed using the Shapiro–Wilk test. Differences between sexes were evaluated using Student's t-test for normally distributed variables and the Mann–Whitney U test for non-normally distributed variables. Differences among the three age groups were assessed using one-way ANOVA for parametric data and the Kruskal–Wallis test for non-parametric data. Descriptive statistics are presented as mean ± standard deviation (SD), along with minimum and maximum values.

RESULTS

This study analysed posteroanterior wrist radiographs of 300 individuals (150 males and 150 females) to investigate morphometric parameters, angular measurements, and wrist-related ratios according to age and sex.

Sex-related comparisons. Analysis revealed that all length measurements were significantly greater in males than in females ($p < 0.001$). Among the angular measurements, the carpal angle was significantly higher in males ($p < 0.001$), whereas no significant sex difference was observed for the RIA ($p > 0.05$).

Among the ratio metrics, the CHR, CRR, and CUR were significantly higher in males than in females on both sides ($p < 0.001$). In contrast, the rCHR did not differ significantly between the sexes ($p > 0.05$) (Table I).

Age-related comparisons. Significant differences were observed in left CH and left CRD, which were lower in the 20–39 age group compared to the 40–59 age group (p <

0.05). Additionally, CRD was lower in the 20–39 age group than in the ≥60 age group for both right and left sides. No significant differences in length measurements were observed between the other age groups ($p > 0.05$). Similarly, angular parameters, including carpal angle and radial inclination, did not differ significantly among the age groups ($p > 0.05$).

Analysis of ratio values revealed significant differences among age groups for the CHR, CRR, and CUR ($p < 0.05$). The CHR and CRR were significantly lower in the 20–39 age group compared to the older groups ($p < 0.05$), with no significant differences between the 40–59 and ≥60 age groups ($p > 0.05$). CUR was significantly lower in the 20–39 group than in the ≥60 group ($p < 0.05$), while no significant differences were observed between the other groups ($p > 0.05$) (Tables II and III).

DISCUSSION AND CONCLUSION

Morphometric evaluation of the wrist in healthy individuals and assessment of age- and sex-related changes in these parameters play a critical role in guiding surgical procedures, monitoring pathological wrist conditions, and optimising orthotic interventions (Namazi & Khaje, 2015). Wrist ratios are calculated from measurements obtained on posteroanterior and lateral radiographs, based on specific

Table I. Comparison of wrist measurements in males and females.

Parameters	Male		Female		
Right Lengths (mm)	Mean±SD	Min-Max	Mean±SD	Min-Max	p
HL	213.01±11.07	186.31-246.04	191.77±9.36	170.02-224.71	<0.001*
CH	39.78±2.82	29.26-46.26	34.36±2.47	29.36-40.62	<0.001*
TMCL	70.25±4.40	60.53-83.16	63.46±3.58	52.86-73.5	<0.001*
SL	25.52±2.87	17.24-33.77	21.14±2.21	14.73-26.72	<0.001*
CL	25.17±2.16	18.28-31.90	21.66±1.74	18.40-27.54	<0.001*
LW	12.90±1.33	8.06-17.01	10.72±1.02	7.26-14.02	<0.001*
CRD	25.04±2.27	17.05-31.64	21.01±1.83	17.27-29.99	<0.001*
CUD	25.81±2.14	19.78-32.33	21.83±1.73	18.10-28.10	<0.001*
Angles (º)					
CA	128.58±6.26	114.58-149.22	125.63±5.62	110.88-144.41	<0.001*
RI	25.15±3.94	13.80-35.10	25.35±4.12	15.04-36.45	0.931
Ratios					
CHR	0.56±0.03	0.46-0.66	0.54±0.03	0.44-0.65	<0.001*
RCHR	1.58±0.09	1.31-1.86	1.59±0.09	1.26-1.84	0.619
CRR	0.35±0.03	0.25-0.45	0.33±0.03	0.26-0.48	<0.001*
CUR	0.36±0.03	0.27-0.43	0.34±0.03	0.27-0.50	<0.001*
Left					
Lengths (mm)					
HL	213.16±10.92	188.35-245.06	191.17±9.07	172.10-227.01	<0.001*
CH	39.78±3.04	28.24-48.15	34.04±2.31	29.25-40.40	<0.001*
TMCL	70.29±4.51	61.26-85	63.65±3.57	52.71-75.27	<0.001*
SL	25.84±2.72	18.16-33.86	21.16±2.09	15.56-26.31	<0.001*
CL	25.32±2.15	18.39-31.10	21.69±1.64	17.37-26.47	<0.001*
LW	13.12±1.32	9.01-17.08	10.74±0.95	8.10-14.15	<0.001*
CRD	25.29±2.09	19.71-30.83	21.22±1.96	17.25-32.51	<0.001*
CUD	25.90±2.18	19.04-31.79	21.78±1.64	18.55-27.74	<0.001*
Angles (º)					
CA	128.47±6.05	112.61-146.06	126.04±5.46	111.12-145.50	<0.001*
RI	25.69±3.86	14.52-36.30	25.85±3.83	14.96-37.44	0.708
Ratios					
CHR	0.56±0.04	0.44-0.67	0.53±0.04	0.44-0.91	<0.001*
RCHR	1.57±0.10	1.30-1.88	1.57±0.09	1.26-1.85	0.848
CRR	0.36±0.03	0.28-0.46	0.33±0.03	0.25-0.55	<0.001*
CUR	0.36±0.03	0.26-0.44	0.34±0.028	0.27-0.48	<0.001*

HL : hand length, TMCL: third metacarpal bone length, CL: capitate length, CH: carpal height, SL: scaphoid length, LW: lunate width, RCD: carpal radial distance, CUD: carpal ulnar distance, RIA: radial ınclination angle, CA: carpal angle, CHR: carpal height ratio, rCHR: revised carpal height ratio, CRR: carpal-radial ratio, CUR: carpal-ulnar ratio, SD:standard deviation, Min: minimum, Max: maximum, *p<0.05, **p<0.001

bony landmarks. In managing wrist pathologies, assessing the degree of carpal collapse using these ratios is important for diagnosis, treatment planning, and follow-up (Ominde *et al*., 2022).

Table II. Comparison of wrist measurements in age groups.

Parameters	20-39 age		40-59 age		≥60 age		p
Right Lengths (mm)	Mean±SD	Min-Max	Mean±SD	Min-Max	Mean±SD	Min-Max	
HL	199.78±14.5	170.20-236.93	204.54±15.07	174.41-246.01	203.28±13.9	174.58-	0.065
CH	36.39±3.66	29.26-46.13	37.51±3.89	29.36-46.23	37.55±3.68	30.15-46.26	0.055
TMCL	66.50±5.39	53.10-80.32	67.26±5.29	52.86-83.16	66.78±4.90	56.10-81.86	0.541
SL	22.73±3.37	14.73-31.42	23.68±3.40	16.92-32.12	23.82±3.17	18.25-33.77	0.055
CL	23.12±2.79	18.28-31.90	23.73±2.54	18.44-29.37	23.39±2.46	18.81-30.64	0.126
LW	11.54±1.63	7.26-16.57	12.06±1.63	8.86-17.01	11.86±1.47	9.54-15.24	0.060
CRD	22.49±2.83	17.27-31.64	23.35±2.94	17.05-29.99	23.44±2.75	18.70-29.10	0.037
CUD	23.28±2.72	18.10-30.55	24.13±2.72	18.58-32.33	24.29±2.89	19.12-29.80	0.026
Angles (º)							
CA	126.82±6.38	110.88-149.22	127.32±6.11	113.16-145.73	127.25±5.69	114.58-	0.806
RI	25.27±4.24	13.80-36.21	25.42±4.22	15.04-36.45	24.86±3.12	16.33-30.18	0.673
Ratios							
CHR	0.54±0.03	0.44-0.63	0.55±0.04	0.44-0.65	0.56±0.03	0.50-0.66	0.026
RCHR	1.58±0.09	1.26-1.84	1.58±0.10	1.31-1.86	1.60±0.08	1.31-1.78	0.150
CRR	0.33±0.03	0.26-0.48	0.34±0.03	0.25-0.45	0.35±0.03	0.29-0.43	0.02*
CUR	0.34±0.03	0.27-0.44	0.35±0.02	0.30-0.43	0.36±0.03	0.30-0.50	0.008
Left							
Lengths (mm)							
HL	199.49±14.3	172.10-234.18	204.52±15.34	176.15-244.48	202.78±14.3	173.56-	0.059
CH	36.17±3.79	28.24-48.15	37.45±4.03	29.25-46.58	37.31±3.89	30.19-47.18	0.029
TMCL	66.60±5.30	53.61-80.96	67.55±5.32	52.71-85	66.15±5.88	42.23-81.30	0.311
SL	22.93±3.39	15.56-31.21	23.89±3.42	17.15-32.55	23.87±3.08	18.96-33.86	0.093
CL	23.16±2.72	17.37-31.10	23.82±2.57	19.06-30.64	23.56±2.55	18.85-30.82	0.135
LW	11.69±1.64	8.10-16.02	12.13±1.68	8.95-17.08	12.03±1.57	9.61-15.91	0.106
CRD	22.69±2.81	17.25-32.51	23.68±2.95	17.89-30.83	23.54±2.70	18.55-28.70	0.022
CUD	23.32±2.72	18.55-30.39	24.18±2.82	19.31-31.79	24.20±2.90	19.55-30.76	0.051
Angles (º)							
CA	126.85±5.92	111.12-146.06	127.36±5.92	111.14-145.50	127.85±5.76	112.61-	0.546
RI	25.98±3.97	14.52-36.30	25.81±3.98	14.96-37.44	25.29±3.26	17.08-31.00	0.520
Ratios							
CHR	0.54±0.03	0.44-0.65	0.55±0.04	0.46-0.66	0.56±0.05	0.44-0.91	0.009
RCHR	1.56±0.09	1.26-1.85	1.57±0.10	1.34-1.88	1.58±0.10	1.30-1.80	0.440
CRR	0.34±0.03	0.25-0.5	0.35±0.03	0.27-0.46	0.35±0.04	0.29-0.55	0.013
CUR	0.35±0.03	0.26-0.43	0.35±0.03	0.29-0.44	0.36±0.03	0.30-0.48	0.019

HL:hand length, TMCL: third metacarpal bone length, CL: capitate length, CH: carpal height, SL: scaphoid length, LW: lunate width, RCD: carpal radial distance, CUD: carpal ulnar distance, RIA: radial ınclination angle, CA: carpal angle, CHR: carpal height ratio, rCHR: revised carpal height ratio, CRR: carpal-radial ratio, CUR: carpal-ulnar ratio SD:standard deviation, Min: minimum, Max: maximum, *p<0.05, **p<0.001

Parameters	20-39 vs. 40-59	20-39 vs. ≥60	40-59 vs. ≥60
Right			
CRD	ND	0.040	ND
CHR	ND	0.048	ND
CRR	0.022	0.016	ND
CUR	ND	0.003	ND
Left			
CH	0.032	ND	ND
CRD	0.010	0.025	ND
CHR	0.05	0.002	ND
CRR	0.022	0.003	ND
CUR	ND	0.006	ND

Table III. Post hoc comparisons of wrist measurements between age groups.

CH: carpal height, CRD: carpal radial distance, CUD: carpal ulnar distance, CHR: carpal height ratio, CRR: carpal-radial ratio, CUR: carpal-ulnar ratio, ND: no difference

The results of this study showed that the morphometry of osseous structures in the wrist region may differ according to age and sex.

Today, various parameters are used clinically to diagnose wrist pathologies. CHR is particularly useful for evaluating carpal collapse, which occurs in conditions such as rheumatoid arthritis and scapholunate dissociation (Feipel *et al*., 1999). Carpal collapse, characterised by a reduction in CH, is associated with wrist pathologies such as carpal instability, rheumatoid arthritis, Kienböck's disease (lunate osteonecrosis), and traumatic wrist injuries (Tang *et al*., 2018; Ominde *et al*., 2022). These conditions can lead to a reduction in CH and CHR.

CHR is the standard method for assessing the degree of carpal collapse. It was first defined by Youm *et al*. (1978) who reported an average CHR of 0.54 ± 0.03, independent of age and sex (Youm *et al*., 1978). Since then, numerous studies have examined CHR across different populations. In a study conducted by Uçan *et al*. (2006) on patients with rheumatoid arthritis, carpal collapse was defined as a CHR value below 0.48. They found that CHR values were lower in the patient group compared to controls and observed carpal collapse in 51.5 % of patients, whereas none of the healthy individuals exhibited collapse.

Nattrass *et al*. (1994) proposed rCHR for cases where the entire third metacarpal cannot be visualised due to technical limitations, such as downward tapering of the radiographic beam, or when the articular surface of the third metacarpophalangeal joint is affected by degenerative joint disease and difficult to measure. This ratio is calculated by dividing CH by the length of the capitate bone. The capitate is preferred because its margins are well-defined and it is rarely affected by pathology (Nattrass *et al*., 1994; Agrawal *et al*., 2019; Ominde *et al*., 2022). Nattrass *et al*. (1994) reported a mean CHR of 0.55 ± 0.04 and a mean rCHR of 1.57 ± 0.05 (Table IV).

Table IV. Comparison with other studies regarding CHR and rCHR.

Author(s)	Country	n	Sex	Age	CHR	rCHR
Youm *et al*., 1978	USA				0.54± 0.03	
Nattrass *et al*., 1994	Canada	100			0.55±0.04	1.57± 0.05
Jafari *et al*., 2012	Iran	150			0.52±3.1	1.5± 0.09
Jehan *et al*., 2019	India	120	M		0.53 ± 0.05	1.49 ± 0.06
			F		0.51 ± 0.03	1.50 ± 0.06
			T		0.52± 0.05	1.50± 0.06
				≤ 40	0.53 ± 0.05	1.50 ± 0.07
				> 40	0.52 ± 0.04	1.49 ± 0.06
Wang *et al*., 2010	Taiwan	261			0.51± 0.03	
Foteva & Poposka, 2010	Macedonia	100			0.53± 0.02	1.56± 0.02
Mohammed Ali, 2009	Egypt	300	M		0. 53±0.03	1.53 ±0.16
			F		0.50±0.07	1.55 ± 0.21
Schuind *et al*., 1992	USA	120			0.53±0.09	
Ominde *et al*., 2022	Nigeria				0.47±0.04	1.36±0.07
Yalçın & Polat, 2022	Türkiye		M		0.52 ± 0.05	1.49 ± 0.1
			F		0.51 ± 0.04	1.5 ± 0.11
			T		0.51 ± 0.06	1.49± 0.1
				18-30	0.51 ± 0.05	1.48 ± 0.11
				31-50	0.52 ± 0.04	1.5 ± 0.1
				>50	0.52 ± 0.05	1.5 ± 0.1
Feipel *et al*., 1998	Belgium	80			0.52±0.07	1.48±0.14
Partap *et al*., 2024	West Indies	200	M		0.486± 0.045	1.47 ± 0.085
			F		0.462 ± 0.050	1.468 ± 0.081
Sarhan *et al*., 2024	Jordan	247	M		0.53 (0.04)	
		138	F		0.52 (0.09)	
		385	T		0.5 ± 0.06	
Bhat *et al*., 2024	India	250	M		0.53± 0.05	
		250	F		0.50± 0.05	
Current study	Türkiye	150	M		0.56±0.03	1.58±0.09
		150	F		0.54±0.03	1.57±0.09
		300	T		0.55±0.03	1.58±0.09

CHR: carpal height ratio, rCHR: revised carpal height ratio, M: male, F: female

Various studies have reported CHR values ranging from 0.50 to 0.55 on average. In our study, the CHR measured using the Youm method was 0.55 ± 0.03, independent of age or sex, which is consistent with the findings from Canadian populations but higher than that reported in other studies. rCHR has been reported in previous studies to range between 1.36 and 1.57. In the present study, the rCHR measured using the Nattrass method was 1.58 ± 0.09, which is higher than the values reported in all other studies (Youm *et al*., 1978; Schuind *et al*., 1992; Nattrass *et al*., 1994; Feipel *et al*., 1999; Mohammed Ali, 2009; Foteva & Poposka, 2010; Wang *et al*., 2010; Jafari *et al*., 2012; Tang *et al*., 2018; Jehan *et al*., 2019; Ominde *et al*., 2022; Yalçın & Polat, 2022; Bhat *et al*., 2024; Partap *et al*., 2024; Sarhan *et al*., 2024) (Table IV).

Studies across various populations have revealed that CHR can vary according to sex and age. Research on Chinese and Nigerian populations has reported significantly higher CHR values in men than in women (Wang *et al*., 2010; Ominde *et al*., 2022). In contrast, a similar study conducted in Macedonia found no significant differences in CHR across age or sex groups (Foteva & Poposka, 2010). Similarly, a study in Egypt observed no significant sex differences but reported a statistically significant increase in CHR with advancing age (Mohammed Ali, 2009).

In a study conducted in India, Jehan *et al*. (2019) and in another study conducted in Türkiye, Yalçın and Polat, no statistically significant differences were found in CHR and rCHR across age or sex groups. In our study, the rCHR value did not vary between age groups; however, CHR was higher in males than in females, with lower values observed in the 20–39 age group compared to other age groups (Jehan *et al*., 2019; Yalçın & Polat, 2022) (Table IV).

These findings indicate that both age and sex should be considered when evaluating CHR. The observed increase in CHR with age in certain populations suggests that age-related anatomical and biomechanical changes may influence this parameter. Although our study identified significant differences in CHR by age and sex, the absence of variation in rCHR suggests that this measure is less sensitive to racial or anatomical differences.

Consistent with our findings, many studies have reported that linear measurements are generally higher in men than in women (Schuind *et al*., 1992; Mohammed Ali, 2009; Jafari *et al*., 2012). Jafari *et al*. (2012) observed that CH, TMTL, LW, and CU measurements were higher in older age groups, whereas Schuind *et al*. (1992) reported the opposite. In our study, no significant differences in length measurements were found across age groups, except for CH and carpal-radial distance (CRD). In particular, left CH and CRD were smaller in the 20–39 age group compared to the ≥60 age group. These discrepancies may be attributable to differences in the sex distribution within age groups in the various studies.

CRR and CUR reflect the positional relationships of the carpal bones relative to the radius and ulna. The ulnar displacement of the carpal bones and alterations in the wrist's centre of rotation can affect wrist biomechanics and the normal range of joint motion. These ratios provide quantitative measures that can predict ulnar-carpal translation, which is often associated with carpal collapse. CUR, in particular, is considered useful for evaluating patients with rheumatoid arthritis (Mohammed Ali, 2009; Foteva & Poposka, 2010; Jafari *et al*., 2012).

In an Egyptian population, CRR was reported as 31.4 ± 3.1 in males and 29.6 ± 2.7 in females, while CUR was 29.7 ± 7.0 and 26.65 ± 8.4, respectively, indicating higher values in males. CRR was 30.77 ± 2.2 in the 20–40 age group and 30.9 ± 2.4 in the ≥40 age group, whereas CUR was 27.75 ± 5.3 and 28.6 ± 5.0, respectively. They reported no age-related difference for CRR, but CUR was higher in the older group (Mohammed Ali, 2009).In our study, both CRR and CUR were significantly higher in males than in females on both sides ($p < 0.001$). CRR was significantly lower in the 20–39 age group compared to older groups ($p < 0.05$), and CUR was significantly lower in the 20–39 group than in the ≥60 group ($p < 0.05$), with no significant differences among the other groups ($p > 0.05$). Contrary to our findings, a study conducted in Macedonia reported that CUR did not change according to age and sex (Foteva & Poposka, 2010).

Distal radius fractures are among the most common injuries encountered in emergency departments and orthopaedic clinics, accounting for 15 %–20 % of all fractures in these settings. Radial inclination is a key parameter in the radiological assessment and monitoring of these fractures during treatment. The primary treatment goals are to restore the natural anatomical structure of the wrist, stabilise the bone, and optimise wrist function, with an emphasis on maintaining radial inclination within the normal reference range (Vatansever *et al*., 2007; Chan *et al*., 2008).

The radial inclination angles observed in our study are generally consistent with those reported in other international studies, particularly in Belgian, Swedish, Chinese, and Malaysian populations (Friberg & Lundström, 1976; Hollevoet *et al*., 2000; Chan *et al*., 2008; Tang *et al*., 2018). However, the values reported in a Mexican population study were significantly higher than those in our study and in other reports (Franco-Valencia *et al*., 2006). These findings highlight the need for population-specific reference values, given the substantial influence of population differences on distal radius morphology (Table V).

In our study, radial inclination did not differ significantly between males and females. This result aligns with findings from the studies of the Turkish population (Yalçın & Polat, 2022; Bilgin *et al*., 2023; Yazıbas¸ı *et al*., 2023) and a multi-ethnic Malaysian population (Chan *et al*., 2008). However, a study of a Pakistani population reported higher radial inclination in males (Khan *et al*., 2023), while another study of a Mexican population reported higher values in females (Franco-Valencia *et al*., 2006) (Table V). Regarding age, our study found that radial inclination values did not change significantly across age groups. These findings are consistent with those reported by Namazi & Khaje (2015), and Yalçın & Polat (2022). However, Yazıbas¸ı *et al*. (2023), observed significant age-related differences in radial inclination among males, with lower values in individuals over 20 years, while no differences were found among females. Similarly, Khan *et al*. (2023), in a study of the Pakistani population, reported a significant relationship between age and radial inclination, with smaller values in individuals aged 19–40 years compared to those aged ≥40 years ($p < 0.05$). These results indicate that age-related morphological changes in radial inclination vary by population and sex.

Table V. Comparison with other studies regarding RIA.

Author(s)	Country	Age	Sex	Side	RIA
Hollevoet *et al*., 1996	Belgium				25.6±3.2
Namazi *et al*., 2015	Iran	20-29			23.9
		30-39			24.2
		40-49			23.6
		50			23.67
Friberg & Lundstrom, 1976	Sweden				25±2.2
Bilgin *et al*., 2023	Türkiye		M		26.8±3.6
			F		26.5±2.9
			T		26.7±3.3
Yazıbası *et al*., 2023	Türkiye		M		23.31±4.10
			F		23.27±3.56
		10-19	M		24.40±3.19
			F		22.81±4.42
		20-65	M		22.28±3.61
			F		23.85±3.71
Yalçın & Polat, 2022	Türkiye		M		23.45±4.13
			F		24.32±4.89
		18-30			24.49±4.32
		31-50			24.19±4.91
		≥50			23.12±4.36
Khan *et al*., 2023	Pakistan		M		24.95±
			F		23.5±1.64
		19-40			23.75±2.02
		≥40			25.75±1.82
Tang *et al*., 2018	China				25.1±2.1
Chan *et al*., 2008	Malaysia				24.8±3.03
	India				27±3.18
	China				24.1±3.77
			M		25.1±3.35
			F		24.9±4.02
Franco Valencia *et al*., 2006	Mexico		M		35.51±4.01
			F		38.15±5.13
Current study	Türkiye		M	R	25.25±3.94
				L	25.69±3.86
			F	R	25.35±4.12
				L	25.85±3.83
			T	R	25.25±4.02
				L	25.77±3.84
		20-39		R	25.27±4.24
				L	25.98±3.97
		40-59		R	25.42±4.22
				L	25.81±3.98
		≥60		R	24.86±3.12
				L	25.29±3.26

RIA: radial inclination angle, M: male, F: female, T: total

The carpal angle was first defined by Kosowicz in 1962. In his study of 466 healthy individuals, irrespective of age, sex, or race, he reported an average carpal angle of 131.5 ± 7.2° (Kosowicz, 1962). Some studies have indicated that congenital malformation syndromes can affect the carpal angle. Kosowicz described a carpal angle of less than 117° as a positive carpal sign, which indicates gonadal dysgenesis (Kosowicz, 1962; Harper *et al*., 1974).

Harper *et al*. (1974), investigated carpal angle variations according to age, sex, and race in 928 Americans. They reported mean carpal angles of 136.75° on the right and 131.5° on the left. The study found that the carpal angle is influenced by several factors: it is larger in Black Americans than in White Americans, larger in males than in females, and increases with age. The researchers also noted that newborns have smaller carpal angles than older children, likely due to incomplete ossification of the carpal bones or variability in the positioning of ossification centres. They suggested that the carpal angle stabilises once ossification is complete (Harper *et al*., 1974).

Hsieh *et al*. (2011) reported that the carpal angle can also be used to assess bone age and skeletal maturation in children. They compared carpal angle values of children who grew up in the mid-1960s with those of children from the mid-2000s and found that the latter group had significantly larger carpal angles (Hsieh *et al*., 2011) .

In a study of a Japanese population, carpal angle was reported to be independent of age and sex (Takahashi, 1967). Similarly, a study conducted in Germany found no age-related changes in carpal angle (Vyhnánek *et al*., 1969). Consistent with these findings, our study observed no significant differences in carpal angle according to age and sex. Compared with other populations, the carpal angle in our study was higher than that reported in the Japanese population but lower than the values reported in Polish, American, and German populations (Kosowicz, 1962; Takahashi, 1967; Vyhnánek *et al*., 1969; Harper *et al*., 1974) (Table VI).

Table VI. Comparison with other studies regarding CA.

Author(s)	Country	Sex	Side	CA
Kosowicz, 1962	Poland			131.5±7.2
Harper *et al*., 1974	USA		R	136.75
			L	131.5
Takahashi *et al*., 1967	Japan			126
Vyhnanek *et al*., 1969	Germany		R	135.7
			L	135.9
Current study	Türkiye	M	R	128.58±6.26
			L	128.47±6.05
		F	R	125.63±5.62
			L	126.04±5.46
			R	127.10±6.12
			L	127.25±5.88

CA: carpal angle, M: male, F: female

Wrist measurements and ratios vary across different populations, influenced by factors such as sex, age, and race. Establishing normal reference values for the wrist according to age and sex is essential, as there is no universally 'healthy' wrist to serve as a reference when both wrists are affected by pathology. Therefore, creating a reference database based on a normal population is necessary for accurately comparing and assessing pathological wrist values.

We believe that this study will help establish a normative reference database for wrist bone morphometry in the Turkish population and contribute to the development of data useful for monitoring the progression of wrist pathologies.

ANDI, Z.A. & UZUN, A. Análisis morfométrico de la articulación radiocarpiana en radiografías posteroanteriores: variaciones relacionadas con la edad y el sexo en una población turca. *Int. J. Morphol., 44(1)*:221-230, 2026.

RESUMEN: Este estudio tuvo como objetivo establecer valores de referencia normales para la morfometría ósea de la articulación radiocarpiana en radiografías posteroanteriores en personas de 20 a 74 años, y analizar cómo estos valores y las proporciones óseas derivadas varían según la edad y el sexo. El estudio se realizó utilizando radiografías posteroanteriores bilaterales de la articulación radiocarpiana de 300 personas sanas. Se midieron las longitudes y los ángulos de los huesos de la articulación radiocarpiana con el programa Horos Medical Viewer, y las proporciones óseas de ésta se calcularon a partir de estas mediciones. Los participantes se clasificaron en tres grupos de edad: 20-39, 40-59 y ≥60 años. Los datos se analizaron según la edad y el sexo. Todas las mediciones de longitud, así como el ángulo carpiano, la relación altura carpiano, la relación carpo-radial y la relación carpo-ulnar, fueron estadísticamente significativas mayores en hombres que en mujeres ($p < 0,001$). El análisis por grupos de edad mostró que los individuos de 20 a 39 años presentaron una altura carpiana izquierda y una distancia carpo-radial menores en comparación con los grupos de mayor edad ($p < 0,05$). Los análisis de proporción revelaron además una altura carpiana, una relación carpo-radial y una relación carpo-ulnar significativamente menores en el grupo de edad de 20 a 39 años, mientras que no se observaron diferencias significativas relacionadas con la edad en los parámetros angulares ni en la mayoría de las mediciones lineales. Las mediciones morfométricas de la articulación radiocarpiana se utilizan ampliamente en el diagnóstico y la evaluación de patologías de la articulación. Por lo tanto, es esencial establecer valores de referencia normales específicos para diferentes poblaciones y grupos de edad. Creemos que nuestro estudio proporcionará una referencia útil para futuras investigaciones en este campo.

PALABRAS CLAVE: Articulación radiocarpiana; Huesos del carpo; Radiografía; Valores de referencia; Turquía.

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